FOREST RESILIENCE, BIODIVERSITY AND CLIMATE CHANGE

To sustain the goods and services that we derive from forests, forest ecosystems must recover following disturbances and not become degraded through the loss of biodiversity. In large part, this means maintaining the resilience of forests through careful management with the clear recognition that the global climate is changing. Maintaining or restoring biodiversity in forests promotes resistance to environmental change and therefore acts to a degree as an essential insurance policy against the expected impacts of climate change. Increasing the biodiversity in planted and semi-natural forests may often have a positive effect on their resilience, their resistance, and their productivity and may also increase other services provided by the forest ecosystem.

What is the concept of resilience as applied to forests?

Resilience is a quality that is commonly associated with people, companies, sports teams and even forests. In all cases, resilience is an inherent capacity to recover from adverse events. Resilience should be contrasted with resistance: while the former is the capacity to recover from a disturbance, resistance is the ability to remain unaffected by it.

In forests, resilience is the capacity to recover from severe disturbance, such as fire or logging, and to return, over time, to a pre-disturbance state. When viewed over an appropriate time span, a resilient forest ecosystem is able to maintain what may be thought of as its "identity", that is, its taxonomic composition, structure, ecological functions, and process rates.

Resistance is the inherent capacity of forests to recover from, or absorb, many minor disturbances while maintaining their characteristics. Forests are resistant to many disturbances: they tend to change little within the range of natural variation, although they may vary slightly over time, as a result of non-catastrophic disturbances such as insect herbivory or minor blowdown. Canopy gaps created by the death of individual or small groups of trees are quickly filled by young trees, for example. Forests may also be resistant to environmental changes, such as changes in weather patterns, owing to the functional redundancy among species (where redundancy refers to the overlapping or duplication of the ecological functions performed by different species in an ecosystem). Redundancy can also help to confer ecosystem resilience and resistance to disease, invasive species, and pests.

Ecosystems may have low resistance to a given disturbance but nevertheless be highly resilient. Grasslands, for example, are not resistant to fire but recover quickly following burning. Generally most well-developed forests, especially primary old forests, are both resilient and resistant to change.

What does biodiversity have to do with it?

As forests change, for example through logging, insect attack, or climate change, managers need to be concerned with restoring them to a condition that will enable them to supply desired goods and services. There is strong evidence that the resilience of a forest ecosystem is tied to its biodiversity. Certain species, in particular, perform key functions in forests and so are essential to the maintenance of forest processes. Pollinators, such as some insects, bats, and birds are examples of highly functional species because without them many plants could not propagate. Similarly, bird predation can often control the abundance of insects, reducing insect herbivory and hence significantly increasing tree productivity. Forest resilience depends, in large part, on such key species and functions being maintained, especially following forest management interventions such as logging.

In the absence of biodiversity there would be no ecosystems and no ecosystem functioning. There is evidence that complex forest

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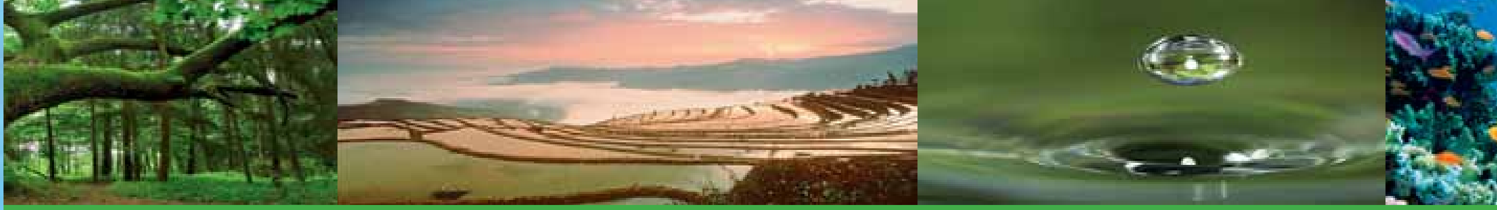

ecosystems are more productive than less diverse ones under the same conditions and that more productive ecosystems are more resilient than less productive ones. Forests comprising relatively few species supply relatively few goods and services and are highly prone to various catastrophes, including disease and invasion. Resilience in forest ecosystems comes from several kinds of biodiversity. First, the genetic make-up of a single species can vary, endowing it with tolerance to a range of climate, moisture and soil conditions. For example, different individuals of the same species of tree growing under different site conditions may differ slightly in their DNA, as a long-term response to their environments. Second, different species might have the same function within an ecosystem, with one species being more abundant and hence the dominant species providing that function. If conditions change sufficiently, the dominant species may be replaced by another as the dominant species performing the function; the important point, however, is that, while the dominant species providing the function changes, the function is not lost to the ecosystem. Finally, across large landscapes, certain species might replace others entirely in a forest system owing to various conditions. This "landscape level" resilience is common in many types of forest, especially among key animal species. Resilience is thus a consequence of multiple aspects of biodiversity and a key characteristic of a forest ecosystem.

The synergistic effects of biodiversity on primary productivity are readily apparent in primary tropical forests with respect to nutrient cycling. Many tropical forests naturally form on nutrient-poor substrates; plants in these ecosystems have evolved the ability to harvest from rainwater the nutrients lacking in the soils. Furthermore, through retention and recycling they build up the stock of nutrients needed to support the high rates of plant growth enabled by moist tropical climates. Plants have special adaptations that serve to conserve nutrients, and a myriad of other fungal, bacterial and animal species aid in their efficient and rapid decomposition and recycling. Overall, biodiversity-related processes serve to increase the productivity and resilience of carbon dynamics in tropical forests.

Forest resilience under global climate change

Superimposed on the many other human impacts on forest ecosystems is global climate change. Most evidence suggests that the resilience of tropical forests may collapse under climate change over the long term, primarily owing to a predicted reduction in rainfall and increased drought. Climate, including temperature, radiation, and moisture, has a major influence on medium- and long-term rates of production, respiration, decomposition, and other forest processes. Climate and weather conditions also directly influence the relatively short-term processes in forests, affecting, for example, the frequency of storms and wildfires, herbivory and species migration. As the global climate changes, forest ecosystems will change because species' physiological tolerances may be exceeded and rates of biophysical forest processes will be altered.

If climate change results in a significant reduction in water availability then the species composition of the forest ecosystem will naturally change and the state (the recognizable condition) of the ecosystem will therefore change as well. For example, conditions may reach a threshold beyond which the vegetation is not sufficiently tall and dense to constitute a closed-canopy forest and there will be dramatic changes in the composition of the dominant plant community. Under severe drying conditions, forests may be replaced by savannahs, grasslands or even deserts.

Ecosystems and forests consist of assemblages of species. Across regions, individual species' ranges reflect their physiological and ecological niches, with the latter reflecting where conditions are advantageous. Species with broad physiological niche requirements may be highly resilient to even significant global climate change. Species with narrow ecological niches are of necessity less resilient but may nevertheless be able to adapt if by chance climate change produces conditions that provide them with an advantage over their competitors. In either case, only species with relatively large gene pools, or the ability to migrate, will be able to adapt. Many species may not have either advantage.

Where population sizes and genetic diversity have been reduced, or the mobility of species is restricted through habitat fragmentation or a natural lack of species mobility, the likelihood of successful adaptation to environmental change such as climate change is diminished. In some cases, populations exposed to a rate of environmental change exceeding the rate at which they can adapt may be doomed to extinction. In the biological realm, therefore, a high level of species and genetic diversity is fundamental to the concept of resilience.

Forests can influence regional climates, depending on their extent. This is particularly true of the Amazon forest. As Earth's climate changes, numerous feedbacks will occur between the climate and forests; these feedbacks will be mediated through albedo, carbon cycle dynamics, energy fluxes and herbivory. Hence, maintaining forest resilience can be an important mechanism for mitigating and adapting to climate change.

TIPPING POINTS

Resilience has its limits. If environmental pressures are too severe, a tipping point is reached whereby an ecosystem changes drastically to an altered and degraded state. A well-studied case is that of the Amazon rainforest, where two interacting tipping points could result in widespread dieback of humid tropical forest in the Amazon.

The first tipping point could be reached through the conversion of forest to agricultural land and burning. This activity could alter regional rainfall, increasing drought and forest fragmentation. These in turn would increase the susceptibility of forests to fire and dieback, leading to a vicious cycle in which fire and dieback become increasingly widespread.

The second tipping point could be reached if, as some climate models project, rainfall in the Amazon is substantially reduced by climate change. Reduced rainfall combined with rising temperatures could result in forest dieback and the reduced transfer of water to the atmosphere, setting off feedbacks that lead to a drier climate in which humid tropical forest is permanently replaced by dry forest and shrub- or grass-dominated vegetation. A recent study of the combined impacts of these two processes suggested that parts of the Amazon may already be close to a forest dieback tipping point.

The Amazon region, especially at its western edge, is one of the most species-rich areas of the world. Widespread dieback of its humid tropical forests would lead to major reductions in species abundance and extinctions. Moreover, widespread fires and forest dieback could lead to massive degradation of sustaining and regulating ecosystem services, such as the loss of carbon stored in vegetation and soils, which could be large enough to influence atmospheric CO_2 concentrations and the global climate significantly while at the same time reducing the amount of oxygen produced by this area.

There is substantial uncertainty about the land use tipping point mechanism but several modelling studies suggest there is a significant risk of dieback when deforestation exceeds 20 per cent to 40 per cent of original forest area.

A precautionary approach would suggest that deforestation should not exceed 20 per cent of original forest area, the use of fire for clearing should be minimized, and global climate warming should be kept below 2°C to avoid this tipping point. Such an approach would require concerted efforts to implement sustainable agricultural practices, establish large protected areas, reduce national and global pressures for increased meat and feed production and other measures. Application of REDD-plus initiatives (see Issue Paper No. 5) could lead to a win-win situation for biodiversity and climate if appropriately implemented. As current trends will likely take cumulative deforestation to 20 per cent of the Brazilian Amazon by, or near, 2020, a programme of significant forest restoration would be a prudent measure to build in a margin of safety.

(Source: Global Biodiversity Outlook 3, 2010; Leadley et al. 2010.)

Looking ahead: how to manage for forest resilience

To a great degree, forest management is aimed at helping forests recover after timber harvesting, by sustaining the properties of the forest ecosystem over the long term. This task has become more complicated as a result of climate change. Maintaining biodiversity is a key to maintaining forest resilience. The biodiversity in a forest ecosystem is linked to and underpins its productivity, resilience and stability over time and space. Biodiversity increases the long-term resilience and resistance of forest ecosystems, increases their primary production and enhances ecosystem stability at all scales. Forests have the capacity to resist environmental change owing to their multiple species and multiple complex processes.

A reduction in biodiversity in forest systems, however, as is characteristic of plantations, for example, has clear implications for the functioning of forest ecosystems and the amounts of goods and services that they can produce. While it is relatively simple to plant trees and produce a short-term wood crop, the lack of diversity at all levels (i.e., genes, species of flora and fauna, and landscapes) in plantation ecosystems reduces their resilience and resistance to disturbances, degrades their ability to provide goods and services, and renders them vulnerable to catastrophic disturbance.

The application of ecological sustainability principles in forest management can provide part of a long-term approach to mitigating and adapting to climate change and maintaining forest resilience. Additional planning and action is also needed, however. The capacity to conserve, sustainably use and restore forests rests on our understanding and interpretation of patterns and processes on several scales, the recognition of thresholds, and the ability to translate knowledge into appropriate management actions in an adaptive manner. Adaptation requires the development, based on predictions and observations, of plausible scenarios for the future. A key aspect of any plan to maintain a flow of forest goods and services is a good understanding of local forest ecology on which to base sustainable forest planning and management.

Maintaining and enhancing forest resilience

The following are suggestions, developed from ecological principles, that can be employed to maintain and enhance long-term forest resilience in the face of climate change.

1. Plan ahead to maintain all elements of biodiversity (genetic, species, community) on all forest scales (stand, landscape, bioregional) based on expected future climate conditions.
2. Maintain genetic diversity in forests through management practices that do not include the selection, based on site type and growth rate or form, of only certain trees for harvesting.
3. Maintain stand and landscape structural complexity using natural forests as models and benchmarks. Emulate the species composition and structure of natural stands by using silvicultural methods that relate to the major functional tree species.
4. Maintain connections among forest landscapes by reducing fragmentation, recovering lost habitats (forest types) and expanding protected area networks.
5. Maintain functional diversity and species redundancy and prevent the conversion of diverse natural forests to monotypic or reduced-species plantations.
6. Reduce non-natural competition by controlling invasive species and reduce reliance on non-native crop tree species for plantation, afforestation or reforestation projects.
7. Reduce the possibility of negative outcomes of assisted regeneration in a given region by allotting to some areas trees of regional provenance, including trees from areas in the region that have climates approximating expected climatic conditions of the future. For example, if reduced rain is predicted for the future, use tree species that are more drought-resistant than local species and provide similar wood value to supplement replanting.
8. Protect isolated or disjunct populations of organisms and populations at the margins of their distributions as source habitats. These populations represent pre-adapted gene pools for responding to climate change and could form core populations as conditions change.
9. Ensure that there are national and regional networks of scientifically designed, comprehensive, adequate and representative protected areas. Build these networks into national and regional planning for large-scale landscape connectivity.
10. Develop an effectiveness monitoring plan that monitors climate conditions and results of post-harvest silvicultural actions, and adapt planning and implementation as necessary.

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